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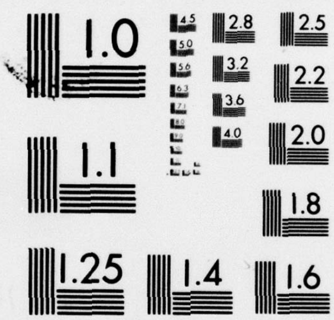

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AN ELECTROMAGNETIC GEOPHYSICAL SURVEY AT AN INTERIOR ALASKA PERMAFROST EXPOSURE

P.V. Sellmann, A.J. Delaney and S.A. Arcone

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Road construction activity near Fairbanks, Alaska, in the late fall of 1977, revealed a large exposure of Fairbanks silt containing numerous massive ice features. These exposures are typical of those found in this region. Thaw, during the summer of 1978, caused the upper ice-rich sections to retreat several meters. Geophysical techniques were utilized over these exposures to determine if resistive anomalies of ice wedge dimension could be detected. Magnetic induction measurements at three intercoil spacings and low-frequency surface impedance measurements were made about 6 m from the edge of each exposure in April 1978 before thaw commenced. The results agree well with observations of the layering, but most individual anomalies are difficult to interpret because the lateral extent of the ice is unknown.

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PREFACE

This report was prepared by P.V. Sellmann, Geologist of the Geotechnical Research Branch, Experimental Engineering Division, and by Dr. S.A. Arcone, Geophysicist, and A.J. Delaney, Physical Science Technician, of the Physical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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The technical review was performed by Dr. D.E. Lawson and Dr. J. Brown of CRREL.

AN ELECTROMAGNETIC GEOPHYSICAL SURVEY AT AN INTERIOR ALASKA PERMAFROST EXPOSURE

P.V. Sellmann, A.J. Delaney and S.A. Arcone

INTRODUCTION

During recent field studies in central Alaska, a newly excavated road cut was visited in the lower part of the Engineer Creek Valley, which is just north of Fairbanks (Fig. 1). This cut was made in the process of rerouting the Steese Highway between Fox and Fairbanks into the Engineer Creek Valley to take advantage of gravel tailings for a stable base and to avoid the ice-rich permafrost terrain in the surrounding area. However, the routing of the new road traversed a peninsula of silt projecting into the valley that was left unexcavated during gold-dredging operations, presumably because of the proximity of bedrock to the surface. A cut through the peninsula for the roadway was excavated using ripper-equipped tractors in the late fall and early winter of 1977 after the ground was completely frozen. The excavation resulted in large vertical exposures extending down into the decomposed bedrock. The exposures of frozen silt contained numerous massive ice features.

This report discusses these examples of ice-rich permafrost and the interpretation of geophysical data obtained from this silt peninsula before thaw commenced. Details concerning this type of ice-rich terrain near Fox are presented by Sellmann (1967 and 1972).

GROUND ICE EXPOSURES

The permafrost features shown in Figures 2 and 3 are representative of the exposures that once bordered many of the valleys in the Fairbanks area during the peak of placer mining operations (Péwé 1975). The old exposures were formed during the process of hydraulically removing the silt in order to reach the underlying gold-bearing gravels. The silt escarpments surrounding the tailings in the valleys north of Fairbanks remain as evidence of these once ice-rich exposures.

Our first inspection of these new exposures was in the spring of 1978 prior to any melting of the ground ice. The exposures consisted of a thick section of reworked valley silt and were approximately 18 m in height and greater than 120 m in length. This silt overlies the decomposed metamorphic bedrock common to the region.

In the eastern side of the road cut (Fig. 3), the southern portion is free of massive ice and parts of it may not be perennially frozen. This contrasts with the northern end, which contains large vertical and horizontal masses of ground ice close to the surface. The vertical ice wedges extend from within 2 m of the surface to approximately the center of the exposure.

The wedges in this and in the western side of the road cut (Fig. 2) bend near their base to form a horizontal ice mass that is continuous across the cut. Ice wedges are not always vertical with depth and often change direction. This transition usually occurs where there is a change in material properties. In this case, the formation of the horizontal band of ice appears to correspond with the transition between the upper ice-rich silt near the surface and the lower silt unit that is free of massive ice but still contains pore ice. The upper silt correlates with the Wisconsinan section described by Péwé (1975) and seen in the CRREL permafrost tunnel (Sellmann 1967). The lower silt unit is composed of Illinoian-age loess.

This distinction between Wisconsinan and Illinoian silt is identifiable in Fairbanks exposures by color and because the Illinoian sections are free of massive ice. The Wisconsinan-age retransported silt is brownish in color in contrast to the greenish coloration of the Illinoian silt. The green coloration is thought to be related to the presence of ferrous iron resulting from ground-water movement during the period this part of the section was thawed prior to the deposition of the Wisconsinan sediments (Péwé 1965).

The Illinoian silt overlies a Precambrian or early Paleozoic schist (known as Birch Creek schist), which is usually severely decomposed in this area. Blocky rubble from this part of the section can be found at the base of the eastern exposure.

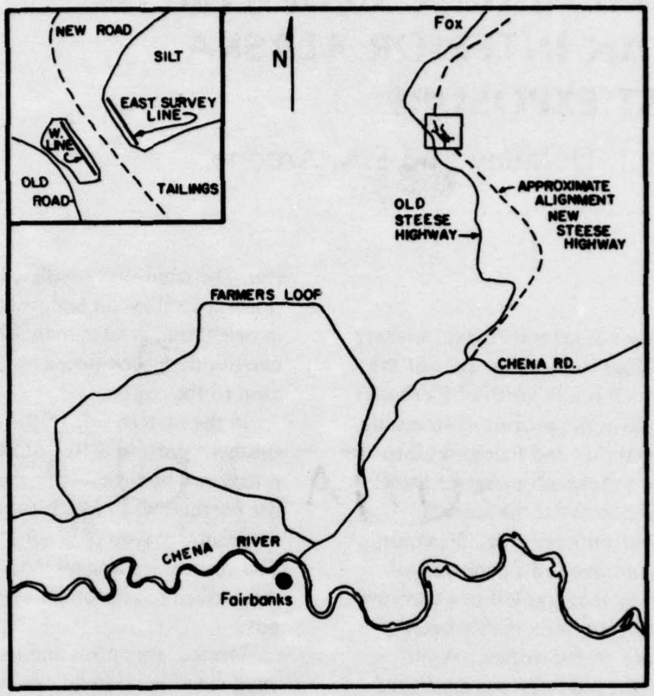

Figure 1. Location map showing Fairbanks area and new Steese Highway road cut.

An interesting aspect of these sizable exposures is the apparent random distribution of the ground ice in both horizontal and vertical extent. The southern end of the eastern exposure is free of massive ice with no surface indication of this fact.

The site was revisited in the fall of 1978 after summer thaw had resulted in considerable bank retreat. The upper part of both exposures had retreated about 4-6 m, modifying and masking most of the original vertical face (Fig. 4). As expected, the ice-free section underwent little retreat.

GEOPHYSICAL TECHNIQUES

This site provided an opportunity to use electromagnetic geophysical techniques to determine whether the ice wedges would produce high resistivity anomalies at the surface. The techniques used employ the principles of magnetic induction and surface impedance. Their operation will be described briefly. More detailed discussions of both techniques are found in Arcone et al. (1979).

In the magnetic induction (MI) method, a small loop antenna generates a magnetic field that penetrates the ground. This field, called the primary field, induces earth eddy currents, which then generate a secondary magnetic field. A second loop antenna then receives both primary and secondary fields. The total received signal is compared with an artificial signal equal to the primary signal to determine earth resitivity. The depth to which the systems discussed here are sensitive primarily depends on the interloop spacing and loop orientation. Three loop separations of 3.6, 15 and 30 m were used which gave approximate penetrations of 6, 11 and 22 m, respectively, in homogeneous ground for the loop orientation used. The loop orientations were horizontally coplanar at 3.6 m and vertically coplanar at 15 and 30 m.

In the surface impedance (SI) method, a comparison is made between the earth tangential electric and magnetic field components of a low-frequency (LF) radio groundwave propagating from a distant, vertically polarized transmitter in commercial use. These field components are the vector sum of the direct surface and indirect subsurface refracted and reflected waves. The subsurface radiation decays exponentially with depth in proportion to the square root of the ratio of ground resistivity to frequency. At 257 kHz, which

South North

Figure 2. Photograph of the western side of the road cut looking north taken in April 1978 before thaw had commenced.

is the frequency monitored, penetration in 1000 ohm-m ground is about 30 m.

The interpretation of the data generated by either the MI or the SI method is based upon the simple geological model of a smoothly layered ground, each layer being homogeneous and of specified resistivity ρ. Such a model generally conforms to the situations shown in Figures 2 and 3 where a layer of Wisconsinan silt overlies a layer of Illinoian silt, which then overlies the Birch Creek schist. When lateral irregularities in resistivity are encountered, severe and confusing fluctuations in the data may result. Only in an isolated disturbance (such as a solitary ice mass) will a resistivity profile give satisfying results (e.g., see Arcone et al. 1978). In the Wisconsinan silt, which is permeated by numerous irregular ice masses, we assumed that in general it would have a higher resistivity than the Illinoian silt and the schist. We also hypothesized that the data might reflect the occurrence and general dimensions of the ice masses.

RESULTS

Two survey lines were established during the spring and were placed approximately 6 m back from the edge of the exposures (Fig. 1). Therefore, the profiles were not directly over the ice seen at the face. The extent of the ice perpendicular to the profiles was unknown in April but, in September, massive ice could still be seen at the northern end of the eastern exposure (Fig. 4). The magnetic induction interloop axes were all parallel with the traverse. The magnetic field of the LF radiowave was perpendicular to the traverse and the earth tangential electric field was therefore parallel to the traverse.

The apparent resistivity and phase profiles are shown in Figures 5 and 6. On both sides of the road cut, the 3.6-m loop spacing usually gave the highest readings. This conforms to the observed high ice content of the Wisconsinan silt, the depth of which exceeds the effective penetration of the primary magnetic field of this (MI) instrument.

The LF phase data suggest that resistivity is slightly increasing with depth, at least through an effective

Figure 3. Composite photograph of the eastern side of the road cut taken in April 1978 before thaw had commenced. The X noted at the base of this figure corresponds to the same location marked by an X in Figure 4.

Figure 4. Composite photograph of the eastern side of the road cut taken in September 1978 following one summer of thaw. The portion of the bank containing massive ice had retreated 4 to 6 m.

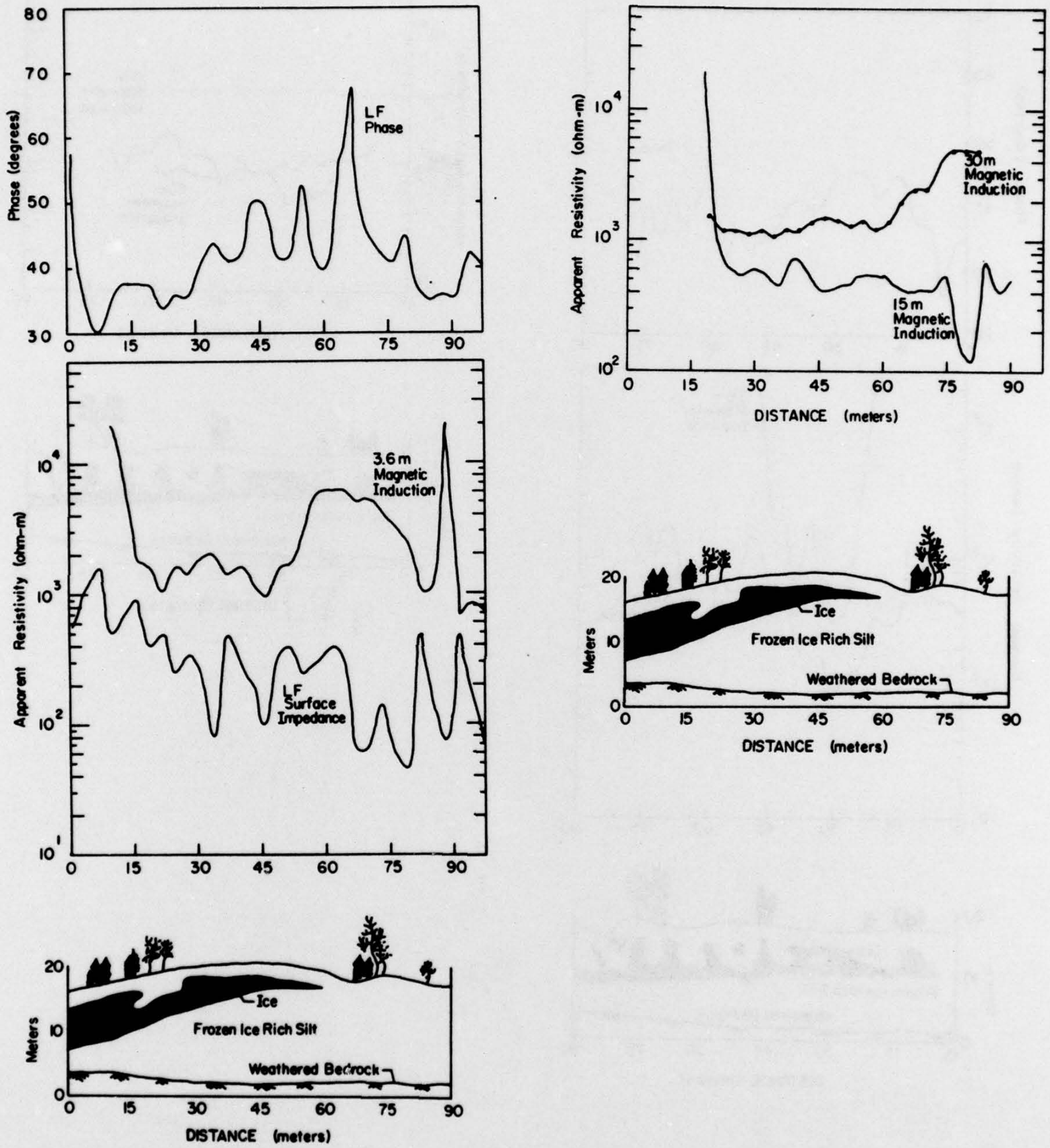

Figure 5. Apparent resistivity and phase profiles obtained over the eastern side of the road cut in April 1978.

depth of penetration of about 10 to 30 m. Since this observation contradicts the contrast expected for the Wisconsinan and Illinoian silt, it therefore implies that the Birch Creek schist must be of high resistivity, or at least more resistive than the Illinoian silt. To verify this, we took 11 LF measurements along the floor of the road cut (the upper level of the schist) between the two exposures. The apparent resistivity ranged from 200 to 2650 ohm-m with an average of 1060 ohm-m. The phase ranged from 34° to 52° with an average of 41°. These resistivity values are higher than those observed at the surface and are higher than

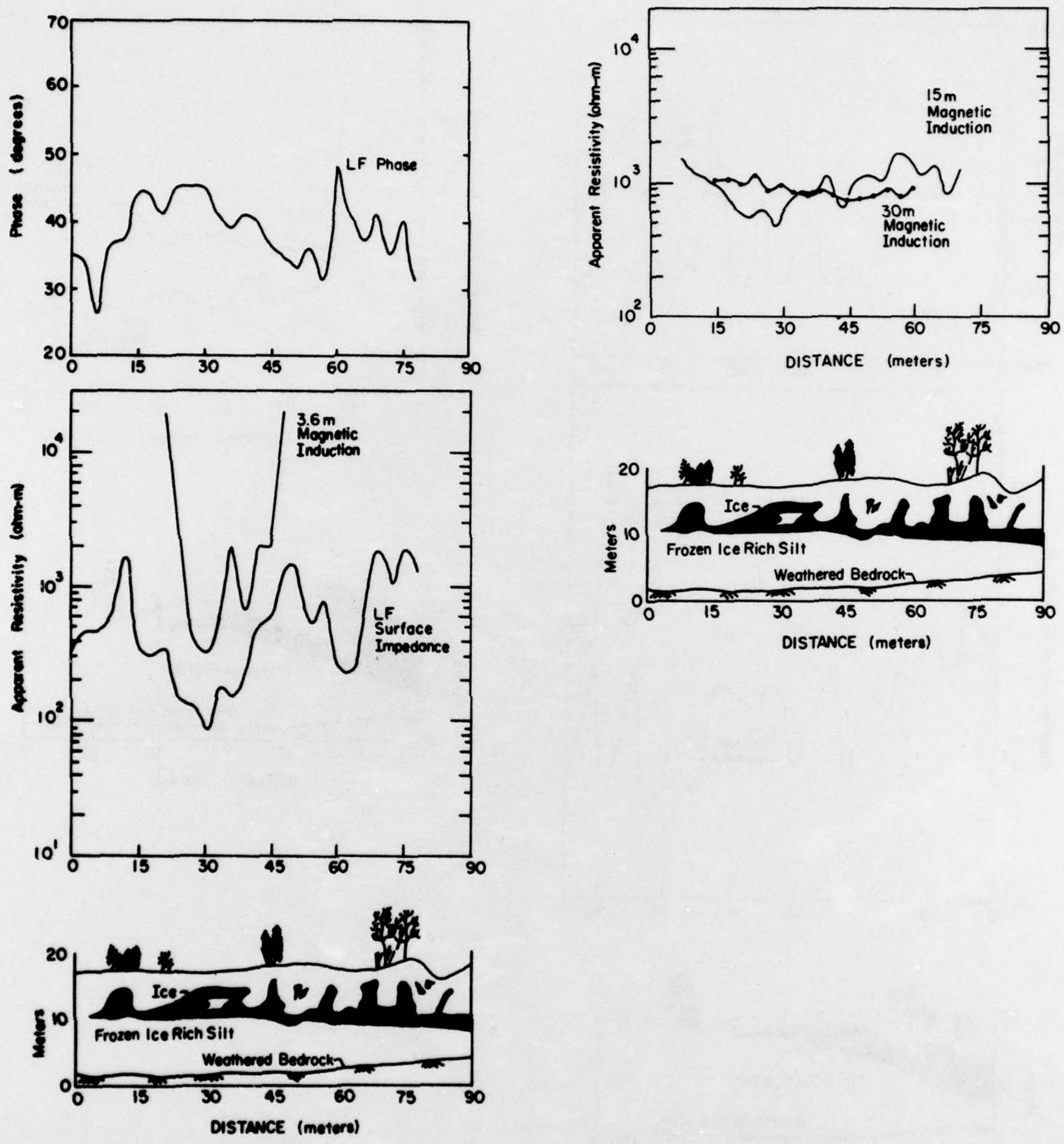

Figure 6. Apparent resistivity and phase profiles obtained over the western side of the road cut in April 1978.

values normally found in the Fairbanks area for the Birch Creek schist. This may indicate that the bedrock at this site is frozen or less decomposed than at other sites. Additional verifications that the Birch Creek schist was generally of higher resistivity than the Illinoian silt may be seen by comparing the 15-m and 30-m profiles for the eastern exposure. For the western exposure, the values are more comparable.

Of particular interest is the correlation of the 3.6-m (MI) and the LF data with the exposed ice masses because these techniques were the least sensitive to depth at this location. The apparent resistivity profiles for these instruments over both exposures show considerably more variation than the 15-m and 30-m profiles. However, they offer no direct correlation with the ice masses except at the northern end of the

eastern exposure. At this location (Fig. 3 and 5), the LF and 3.6- and 15-m MI techniques all show increasing resistivity over this prominent ice feature. The depth of penetration of the 30-m MI was probably too great to be influenced by this feature.

In general, the lack of correlation between the resistive anomalies and the ice masses can be explained as follows:

1) Where resistivity was generally 20,000 ohm-m or more, the MI instrument was insensitive to resistivity changes. This occurred over approximately 30% of the western exposure.

2) The interloop axis of the 3.60-m MI instrument was oriented parallel with the traverse and, therefore, perpendicular to the probable trend of some of the ice masses. Greater sensitivity of the instrument might have been achieved if it had been oriented parallel with the trend of the ice. Also, the 3.6-m loops were horizontally coplanar. Later studies by Arcone et al. (1979) have shown that vertically coplanar loops give greater instrument sensitivity to shallow, linear features.

3) The surface impedance method is subject to the phenomenon of "current streaming," wherein ground currents excited by the radio groundwave may deviate from the transmitter direction or distribute themselves asymmetrically in order to avoid highly resistive inhomogeneities. Such distributions violate basic assumptions used in the data interpretations.

4) The highest degree of variability was found in the LF data and may reflect this method's greater sensitivity in resistive ground, as discussed by Arcone et al. (1979).

5) Most important, neither the actual three-dimensional extent of the ice nor the geology directly beneath the profile, was known. Had the data been taken right at the edge of the exposure, the data would have been biased by the discontinuity of the cut itself. As it was, this discontinuity probably affected the LF and the 30-m MI data.

CONCLUSIONS

The methods used gave results that agreed well with the observed layering present. This is to be expected because vertical stratification of horizontal layers is the basis for interpreting the data produced by these techniques. The resistivity anomalies measured in the uppermost layer did not correlate well with the ice masses observed at the exposure, which was about 6 m from the profile. In the SI (at LF) and MI studies by Arcone et al. (1979) over ice masses, good qualitative correlations were often obtained where direct subsurface information was available. This lack of control, then, was probably our greatest difficulty in interpreting the measured resistivity anomalies.

We recommend that, when using the MI method, all the available loop configurations and intercoil axis orientations should be used because many ice masses have preferred orientation. Such versatility at a single frequency is not offered by the SI method because with this method the instrument antennas must be fixed with respect to the transmitter.

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